Studying the effectiveness of a modernized cathodic protection system for an offshore platform

Krzysztof Zakowski
Department of Electrochemistry, Corrosion and Materials Engineering, Gdansk University of Technology, Gdansk, Poland

Abstract

Purpose – The aim of this paper is to present the modernization of an old cathodic protection system installed on the legs of an offshore platform and to discuss the results of the research performed in order to investigate the anticorrosive effectiveness of this solution.

Design/methodology/approach – The modernization of the cathodic protection system consisted of connecting to the platform legs a sacrificial anode system placed at the sea bottom. The effectiveness of the modernized system was assessed on the basis of the measurements of the potential profiles of the platform legs, i.e. the distribution of their potential over the entire length.

Findings – After connecting sacrificial anode systems, the potential of the legs kept changing towards more negative values. The extent of cathodic polarization increased, and already after a week the potential of the legs fell within the range of full cathodic protection almost along their entire length. The polarization was higher at the lower parts and decreased close to the water surface, which was a result of the distance of a given fragment from the anodic system. The results of the measurements confirmed the correctness of the design assumptions and the effectiveness of the performed modernization.

Originality/value – The results obtained show that the modernization of the cathodic protection system on the legs of an offshore platform consisting of connecting sacrificial anode systems placed at the sea bottom can ensure the achievement of full cathodic protection potential for long legs (these were 80 m long in this study).

Keywords Cathodic protection, Offshore, Platform, Sacrificial anodes, Retrofit cathodic protection system, Construction works, Corrosion protection

Paper type Research paper

Introduction

The cathodic protection of marine structures is performed by means of sacrificial anodes, impressed current systems or using hybrid systems consisting of a combination of the two. Cathodic protection current flows from the anode via the electrolyte to the surface of the protected metal through insulation defects, i.e. holes or pores in the coating. As a result, the electrochemical potential of the protected metal changes to a more negative value (cathodic polarization). The metal is completely protected against corrosion when it becomes polarized to the so-called protection potential. For steel, this value should be $+0.25\,V$ vs Zn/seawater electrode, which corresponds to a value of $-0.80\,V$ vs Ag/AgCl/seawater reference electrode.

For offshore structures in the petroleum industry, it is recommended that sacrificial anodes are used cathodic protection (Standards Norway, 2007). On oil platforms across the world, the number of impressed current systems is decreasing, not only as a result of the aforementioned recommendations but also as a result of high maintenance, servicing and supervision costs for the operation of impressed current systems (Khazraei, 2006). Cathodic protection systems operating for ten years or longer do not always ensure the polarization of the protected structure to the protective potential, due to partial wear and tear and loss of mass of the sacrificial anodes. Modernization of the installation, which consists of installing new, additional elements without the necessity of towing the platform to the shipyard, is an alternative to the replacement of all anodes with new ones. Such a solution is more rational and has a better economic justification.

Three solutions are available for the modernization of the cathodic protection system of the offshore platform legs via the use of sacrificial anodes (Morgan, 1987):

1. *Replacement of sacrificial anodes with new ones*. This is a very expensive solution; it is also irrational, if the original sacrificial anodes are only partially worn.
2. *The installation of additional, bracelet-shaped anodes on the steel poles of the leg structure*. This solution is relatively rarely used because of the high cost of anode production in this shape, the high cost of their installation on the platform legs, possible excessive cathodic polarization of the steel directly under the anode and the likelihood of bacterial development promoted by poor oxygenation under the bracelet, caused by a limited water flow.
3. *Increasing the level of cathodic polarization of the legs by placing a group of sacrificial anodes on the sea bottom next to the platform leg*. The group of sacrificial anodes is usually constructed in the form of a spatial system connected to the protected leg by means of a cable. The number of anodes is usually selected for ten to 15 years of operation. Such a solution is quick to install and is much cheaper than the alternatives.

In the present study, the practical application of the last of the aforementioned solutions is presented and the results of the

[DOI 10.1108/00035591111148876]

research performed to assess the effectiveness of the CP system before upgrading is discussed.

Modernization of the cathodic protection system of a platform

Description of the structure

The example platform was located on the bottom of the Baltic Sea and has three steel legs with the configuration of an equilateral triangular cross-section. Load-carrying poles are situated in the vertices of this triangle, which are connected with each other with a lattice structure made of pipes. The depth of the sea at this location was approx. 80 m. The immersed surface area of each leg was approx. 1,800 m^2. Before setting the platform, 20 years ago, the platform legs were protected against corrosion with a paint coating and by cathodic protection using sacrificial anodes. The paint coating consisted of four layers of paint, with a total nominal thickness of 300 μm. This protection conforms to coating category II, which includes coatings at least 250 μm in thickness consisting of one or more layers of paint (DNV, 2005). Aluminium sacrificial anodes were distributed evenly along the entire length of the legs and were welded to them. The number of anodes and their weight were selected for a 30-year period of operation.

The concept of technical solutions of the modernization

Periodic measurements of the effectiveness of the cathodic protection showed that the sacrificial anodes did not ensure adequate polarization of the structure (something which will be discussed below in the experimental section). This was caused by partial consumption of the anodes. The loss of their weight (solutionization as a result of providing cathodic protection current) and consequent reduction in size caused an increase in the resistance of the anodes which decreased the intensity of the protective current and reduced the degree of the cathodic polarization of the legs. On the basis of the visual inspection, using a remotely operated underwater vehicle, it was found that the wear and tear of the anodes was approx. 50 per cent. Additionally, it was found that there was no stray current interference – joint time/frequency analysis of the measured potential of the leg, using the short time Fourier transformation, was performed (Darowicki and Zakowski, 2004; Zakowski, 2009). The results obtained showed the presence of only a 60-Hz frequency component in the measured signal. This was associated with the operation of the AC generators and electrical equipment on the platform (60 Hz system).

As a result of the partial wear and tear of the anodes, the concept of using a "supplementary" system aimed at extending the cathodic polarization of the legs to achieve full cathodic protection was introduced. Taking into account: the specificity of the structure, technical possibilities (the necessity to conduct work at open sea at the location of the platform) and the assumed platform operation time – for ten years – the concept of the application of sacrificial anodes placed on the seabed was devised. The installation of two systems was planned for each leg – the systems were to be placed at both its sides, at a distance of approx. 20 m, in order to obtain a favourable distribution of the cathodic protection current along the entire length of the legs. The advantages of the adopted solution was the ease and speed of implementation, as compared to the time-consuming and expensive underwater welding of single anodes to the legs along their entire length and also the possibility of selecting the amount of the anode material suited to the expected platform operation time. It was noted from literature reports that such solutions had been introduced elsewhere, e.g. on platforms operated in the North Sea (Morgan, 1987) and in the Gulf of Mexico (Britton, 2004) for the legs up to 50 m long.

Design parameters of the supplementary system

The demand for cathodic protection current is determined by multiplying the surface area of the structure by the design current density.

The design current density is calculated by multiplying the current density needed for the protection of bare steel under the existing environmental conditions (geographical region, depth of immersion) by the coating breakdown factor f (CEN – European Committee for Standardization, 2001). This describes the reduction of the required density of the cathodic protection current as a result of the application of the coating. If $f = 0$, coating is considered to provide full insulation, and if $f = 1$, coating has no protective properties and the design current density is the same as for bare steel. The value of the factor is calculated from the dependency:

$$f = a + b \cdot t, \tag{1}$$

where: t is the age of the coating in years, and the constants a and b depend on the category of the coating and environmental conditions.

For the geographical region where the platform is located, the recommended mean density of the cathodic protection current for bare steel amounts to (DNV, 2005):

- for depths of up to 30 m: 0.100 A/m^2; and
- for depths of over 100 m: 0.080 A/m^2.

Taking into consideration the design current density (connected with the coating breakdown factor) and the interaction with the original partially consumed sacrificial anodes, the demand for additional cathodic protection current for a single leg was determined to be 40 A. The total weight of the aluminium sacrificial anodes for an assumed ten-year period of operation was determined at approx. 2,500 kg for each leg (half of this weight in each of the two anodic systems planned for a single leg).

Sacrificial anodes systems

The anode systems were designed in the form of a truncated cone. The lateral surface of the cone was formed by the sacrificial anodes AlZnIn with a length of 1.5 m (length of the anode with a core – 2.4 m) and a net weight of 45 kg (without a core). The construction configuration of the system made it possible to install it using a steel rope and ensured the stability of the system on the seabed. The parameters of the anode: potential vs Ag/AgCl electrode were: −1,120 mV, consumption rate: 3.5 kg/(A × year) and electrochemical capacity: 2,580 A × h/kg.

The resistance of a single anode was determined by the dependency (DNV, 2005):

$$R_a = \frac{\rho}{2\pi L} \cdot \left[\ln\left(\frac{4L}{r}\right) - 1 \right] \tag{2}$$

where:

ρ Seawater resistance.
L Length of the anode.
r Radius of the anode.

The calculated resistance of the anode amounted to approx. 100 mΩ. The resistance of the entire anodic system, consisting of 30 anodes, was 4 mΩ.

The electrical connection of the anodic system with the platform leg was made using polyurethane insulated sea water resistant copper cable - ESL 016357 Rev 00 Round cable $1 \times 150\,mm^2$. A large cross-section of the cable was selected in order to ensure appropriately low resistance, which amounted to 8 mΩ (high resistance would cause a decrease in the protective current intensity from the anodic system). A photograph of the anodic systems when prepared for the installation is shown in Figure 1.

Test methodology

Measurements of the potential profiles of the platform legs, indicating the distribution of the potential on the legs along their entire length, constituted the basic measurement. The measurements were repeated on several occasions: before devising a technical design for the modernization of the cathodic protection system, just before the installation of the first anodic system (the initial state), during the installation of subsequent anodic systems (the effect obtained at subsequent stages of the modernization) and after the performance of the entire installation (the complete effect). The potential was measured using a Zn/seawater reference electrode that was lowered along the entire length of the leg. The electrode was made of pure zinc in the form of a 30-cm long cylinder with a diameter of 2 cm. Before making the measurements, the electrode was immersed in seawater for 24 h. Its potential was verified in respect to the Ag/AgCl standard electrode. The values of the potentials were measured using a digital recorder with an accuracy of 0.01 mV. The sampling frequency was 4 Hz (four readings per second).

Before devising the technical design of the system upgrade, a test cathodic polarization of the platform leg was performed using an external source of direct current. These tests were performed to verify the polarizing capacity of the legs, i.e. to what extent additional impressed current increased the extent of cathodic polarization. A DC power supply and an auxiliary magnesium alloy cylindrical polarizing anode with a diameter of 10 cm and the length of 50 cm were employed. The anode was connected to the positive pole of the current source and the platform leg was connected to the negative pole. The anode was placed at a depth of 40 m (half the height of the immersed part of the leg) at a distance of approx. 15 m from the leg. The intensity of the polarizing current was 9 A. The test was conducted under cyclic polarization conditions, i.e. the source of current was repeatedly turned on and off. The following procedure was employed: the reference electrode was moved 5 m down the leg, next the flow of polarizing current was turned on for 1 min, after turning the current off the electrode was moved down another 5 m, the polarizing current was turned on for 1 min, etc. During the performance of the aforementioned activities, the potential of the leg was acquired on a continuous basis using a digital recorder with the sampling frequency of 4 Hz.

Figure 1 Systems of sacrificial anodes used for the modernization of the platform cathodic protection system

Results

Figure 2 shows the potential profiles of the platform legs obtained during the preliminary tests (approx. half a year before the modernization of the system). They illustrate the distribution of the potential distribution along the entire length of the platform leg.

Figure 3 shows the potential profile of a platform leg performed during the preliminary tests under test cyclic cathodic polarization.

Figures 4-6 show the potential profiles of the individual legs of the platform, measured after the installation of supplementary anodic systems.

Discussion

The effectiveness of the protective action of the old sacrificial anodes was evaluated on the basis of the potential profiles

Figure 2 Potential profiles of the platform legs obtained during the preliminary tests

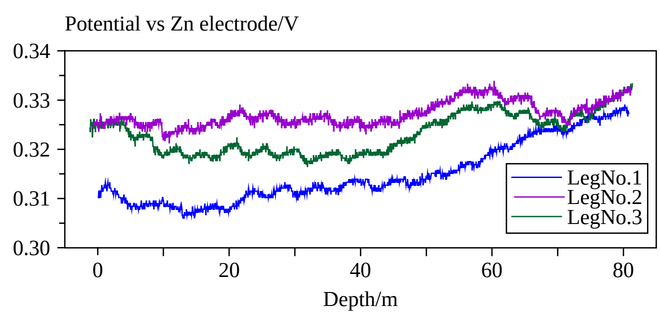


Figure 3 Potential profile of a platform leg performed during the tests for cathodic polarization in the mode of the interrupted operation of the source of current (protective current intensity 9 A)

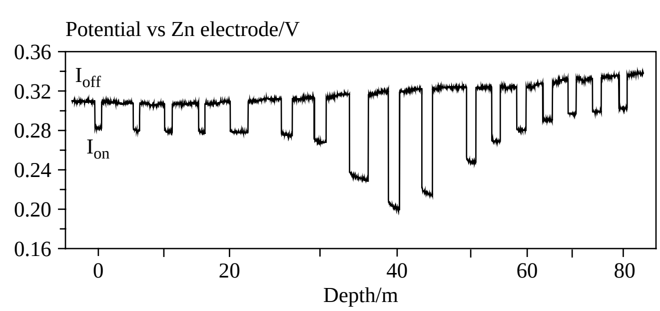


Figure 4 Potential profiles of leg no. 1 after installation of the supplementary anode systems on the seabed

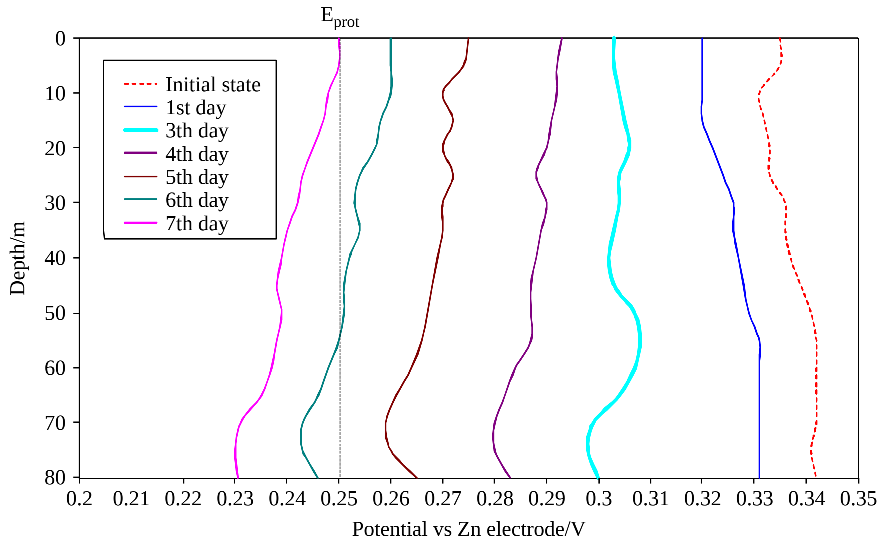
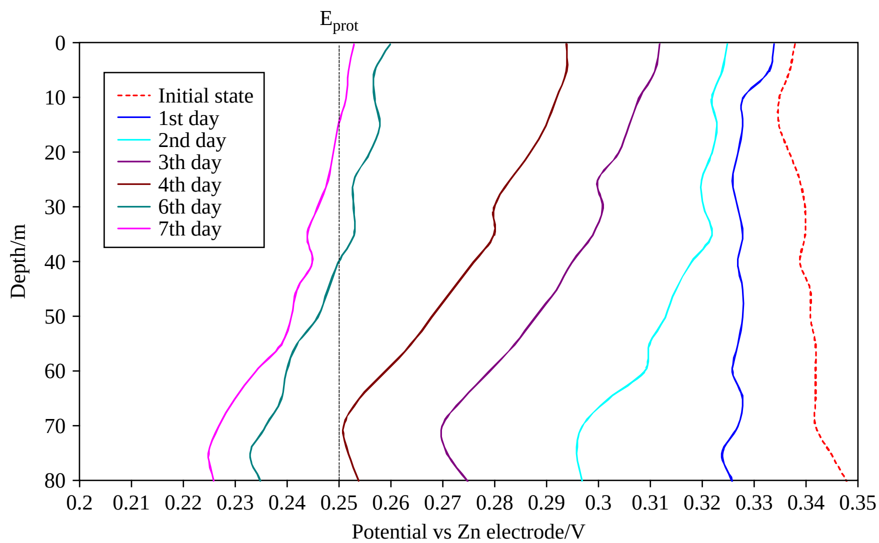


Figure 5 Potential profiles of leg no. 2 installation of the supplementary anode systems on the seabed



shown in Figure 2. The values of platform leg potentials fell within the 0.30-0.34 V range vs Zn/seawater electrode. This meant that full cathodic protection was not being achieved, and that the potential of the most weakly polarized fragments of the legs deviated from the full cathodic potential (i.e. 0.25 V) by approx. 90 mV. A slight increase in the value of the leg potential together with an increase in the depth can be observed. This effect was the most noticeable on leg no. 1 where the difference between the potentials of the lower and upper section of the leg amounted to approx. 25 mV.

The results of the measurements performed during the cathodic polarization test (Figure 3) show stepwise changes in the potential to more negative values after turning on the polarizing current (I_{on}), as compared to the initial state (I_{off}). The potential of the leg facing the polarizing anode (at the depth of 40 m) was changed by approx. 120 mV. The lowest change in potential occurred near the surface of the water and close to the bottom of the leg and amounted to approx. 30 mV. The results obtained showed that additional impressed current increased the degree of cathodic polarization on the legs quite easily. The extent of polarization on the structure depended on its distance from the anode, which can be described by the following dependency:

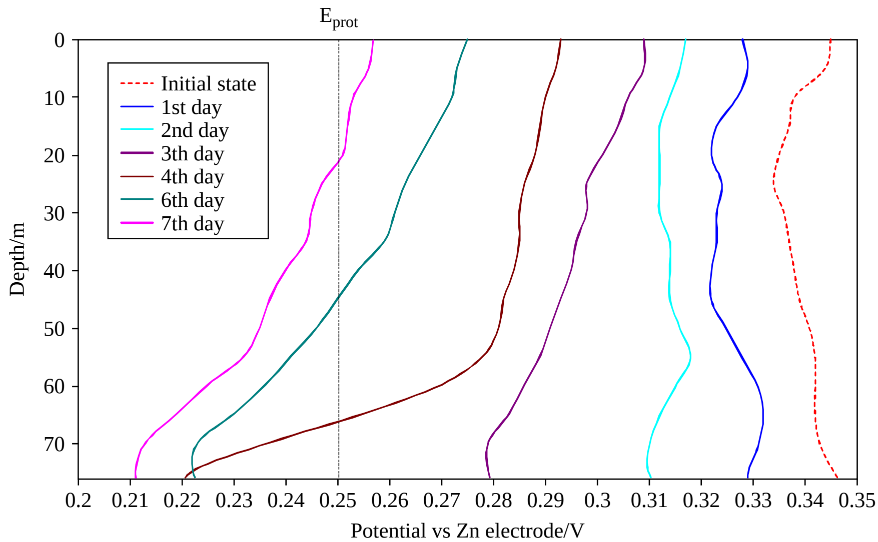
$$\Delta E_x = \Delta E_o \cdot e^{-\alpha X} \quad (3)$$

where:

- ΔE_o Change of the potential at the point closest to the anode (namely drainage point).
- ΔE_x Change of the potential at a point distant by X from the drainage point.
- α Coefficient of current distribution.

The α coefficient depends largely upon the barrier properties of the paint coating. The better the condition of the coating,

Figure 6 Potential profiles of leg no. 3 installation of the supplementary anode systems on the seabed



the flatter is the potential distribution curve and the larger the degree of the anodic protection. The extent the cathodic polarization obtained during the test polarization along the entire length of the leg shows that the barrier properties of the existing coating were relatively weak.

The potential profiles in Figures 4-6, registered during the performance testing of the upgrading of the installation, exhibit a gradual change in the potential of each leg towards more negative values, both after the installation of each subsequent anodic system and subsequently. After connecting all anodic systems, leg no. 1 was the most polarized (Figure 4). Polarization to the level of protective potential occurred along its entire length. The change of the potential, as compared to the initial state, amounted to approx. 100 mV on the lower section of the leg and approx. 80 mV at the upper section. The distribution of the potential along its entire length was the least differentiated of all the legs.

The potential of leg no. 2 (Figure 5) and leg no. 3 (Figure 6) was distinctly more electronegative at the bottom than on the upper section after the installation of all anode systems. Such a distribution of the potential was connected with an increase in the distance to the sacrificial anodes systems and to the presence of metal pipes protecting the production risers. These absorb some current from the cathodic protection system, which is why less of it reaches the upper parts of the legs. However, the obtained polarization results were completely satisfactory. Immediately after the installation of all of the anode systems, a week after the installation of the first of them, the upper portions of these legs were polarized to the more positive potential by only 20 mV than the value for full cathodic protection.

With time, an increase in the cathodic polarization of the legs of the platform is expected, until full cathodic protection along their entire length is obtained. An increase in the cathodic polarization of the structure after commissioning the protection installation may last several weeks, sometimes even several months. On the one hand, it results from the gradual assumption of their functions by the anodes after the initial period of the operation, and, on the other hand, it depends on the size of the protected surface area of the construction and the condition of the protective coating. The larger the surface area and the worse barrier properties of the coating, the longer the time required for the polarization of the structure (Peabody, 2001). Moreover, the formation of layers of non-conductive calcareous deposits on the steel surface favours an increase in cathodic polarization (Zamanzade *et al.*, 2007). These reduce the surface area that needs to be protected (acting as a protective layer) and reduce the rate of the diffusion of dissolved oxygen on the steel surface, thus reducing the demand for cathodic protection current. The precipitation of carbonates occurs as a result of the increase in alkalinity of the environment near the surface of the protected steel as a result of the occurrence of cathodic reactions. The compactness of the layer of the deposits depends on how electronegative the potential of the cathodically protected steel structure is (Neville and Morizot, 2002).

Conclusions

The inclusion of supplementary assemblies of sacrificial anodes placed on the sea bed can be an effective method for upgrading the existing cathodic protection of platform legs, where the old sacrificial anodes provide insufficient current for polarizing the structure to reach the protective potential.

The use of this approach made it possible to obtain a satisfactory effect on the cathodic polarization on platform legs with a length of 80 m that were immersed in the sea. After the installation of anodic systems, the level of full cathodic protection of one leg was reached in just a week, and the potentials of the upper portions of the two remaining legs deviated from the protective potential value by only 20 mV. However, these were not final operational potential values, as after startup of the cathodic protection installation; the degree of cathodic polarization always increases. This process may last several weeks, or even months, due to the large surface area of the protected structure and a relatively bad condition of the protective layers. Moreover, the process of the formation of non-conductive calcareous deposits that are formed on cathodically protected steel in the seawater environment will favour the increase of the polarization.

References

Britton, J. (2004), "Offshore cathodic protection system management: a 21st century approach", available at: www.stoprust.com/4offshorecp.htm

CEN – European Committee for Standardization (2001), "Cathodic protection for steel offshore floating structures", European Standard EN 13173, CEN – European Committee for Standardization, Brussels.

Darowicki, K. and Zakowski, K. (2004), "New time-frequency method of detection of stray currents interference on metal structures", *Corrosion Science*, Vol. 46 No. 5, pp. 1061-70.

DNV (2005), "Cathodic protection design", Recommended Practice DNV-RP-B401, Det Norske Veritas, Bærum, January.

Khazraei, M.A. (2006), "Short history of cathodic protection for fixed offshore structures", *Journal of Corrosion Science and Engineering*, Vol. 9, Preprint 14.

Morgan, J. (1987), *Cathodic Protection*, 3rd ed., NACE, Houston, TX.

Neville, A. and Morizot, A. (2002), "Calcareous scales formed by cathodic protection – an assessment of characteristics and kinetics", *Journal of Crystal Growth*, Vol. 243, pp. 490-502.

Peabody, A.W. (2001), *Control of Pipeline Corrosion*, NACE International, Houston, TX.

Standards Norway (2007), "Cathodic protection", 3rd ed., NORSOK Standard M-503, Standards Norway, Olso, May.

Zakowski, K. (2009), "The determination and identification of stray current source influences on buried pipelines using time/frequency analysis", *Anti-Corrosion Methods and Materials*, Vol. 56 No. 6, pp. 330-3.

Zamanzade, M., Shahrabi, T. and Yazdian, A. (2007), "Improvement of corrosion protection properties of calcareous deposits on carbon steel by pulse cathodic protection in artificial sea water", *Anti-Corrosion Methods and Materials*, Vol. 54 No. 2, pp. 74-81.

Corresponding author

Krzysztof Zakowski can be contacted at: krzysztof.zakowski@pg.gda.pl